File 5

TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 519

FORCE MEASUREMENTS ON AIRPLANES

By F. Seewald

From Zeitschrift für Flugtechnik und Motorluftschiffahrt
October 7, 1928

Washington
June, 1929

T.M. 519 #2

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 519.

FORCE MEASUREMENTS ON AIRPLANES.*

By F. Seewald.

The task clearly assigned to aviation in its present state of development can be roughly summarized as follows. It involves the creation of aircraft satisfying all the conditions of safety and reliability which we are now wont to claim for other means of transportation and also includes an increase in the pay load. It is chiefly a problem of technical research involving the improvement of the flight characteristics and strength with the lowest possible weight. This is undoubtedly the ultimate purpose of all new aircraft designs. On this basis the development of an airplane and the flights made with it are to be regarded as an attempt to come one step nearer the desired goal. Success will necessarily depend on the obtention of all the possible data from these expensive tests.

Most of the data are obtained through the fact that every aircraft reveals its characteristics in flight. In many cases, however, it is impossible to account for these characteristics. Only a general law would enable us, however, to take advantage of the experience gained. Aside from the preliminary scientific work, those tests are the most helpful which, after the completion of an airplane type, enable us to determine its true charac-

*"Ueber die Messung der Kräfte an Luftfahrzeugen," from Zeitschrift für Flugtechnik und Motorluftschiffahrt, October 7, 1928, pp. 474-481.

teristics and to express numerically the effect of the various components on the characteristics of the whole airplane.

Progress can of course be made without such tests. If enough airplanes are made and if their efficiency is determined in each case, general laws will be eventually discovered. By this method, however, the tests are necessarily more numerous and expensive. Especially in Germany, the most essential phenomena of an aircraft should be classified according to their origin and then measured. Information can be thus obtained in a quicker, cheaper, and more reliable way than would otherwise be possible.

With this idea in mind, I have regarded it as one of the most important tasks for my division of the D.V.L. (German Institute for Aeronautic Research) to attempt the solution of this problem. I will now inform you as to how far this attempt has been successful. I hardly need to say that I do not regard this very difficult and extensive problem as being anywhere near solved. I think I can show you some results, however, which indicate that the problem is not so hopeless as it is often regarded.

In the first instance it is very important to separate airplane performances into two main groups, that of the power plant and that of the airplane proper. Certain performances specified in contracts, such as the ceiling, are based on the assumption that the engine develops a given power. If these performances

are not attained, which happens in some cases, no adequate reason can usually be given for the failure. The engine designer is generally firmly convinced that his engine satisfies all the requirements and so is the airplane designer. Lastly, the propeller designer never doubts the efficiency of his propeller.

It has often been attempted to solve this problem by measuring the forces between the airplane and the propeller or the moments between the engine and the propeller, but all previous efforts to insert force-measuring devices, such as measuring hubs, between the engine and the propeller have failed to be entirely satisfactory. Reports on the numerous tests made abroad are so incomplete, that it is impossible to obtain any correct understanding of them. The only data available in Germany were obtained with the old D.V.L. measuring hub, and these data were the main factor in the design of the two new measuring hubs which were shown at the "I.L.A." (1928 International Aeronautic Exposition in Berlim), and which will now be briefly described.

Before making these measuring hubs, tests were carried out with various measuring devices for the purpose of finding a method to transmit the test results electrically to the post of observation. After many fruitless attempts, it was eventually decided to return to the fluid measuring box which, on account of its simplicity and reliability even under the most difficult conditions of operation, is superior to all other devices available for this purpose. There is, however, some difficulty

in connecting the rotating propeller or hub with the stationary recording device in the observer's cockpit.

There are two reasons against rotating the measuring box with the propeller. In the first place, the pressure pipe can be run from the pressure box to the observer's cockpit without being carried around the propeller. In the second place, the accuracy of the measurement is increased, owing to the following reasons. The forces exerted between the propeller and the crank shaft are not constant, due to the irregular running of internal combustion engines. When the box, in which the pressure is measured, is of the rotating type, its connection with a stationary pipe requires the use of a gasket which, however, is never quite tight. Consequently, a certain amount of the fluid leaks through, especially at maximum pressure, and the pressure in the pipe decreases. Thus, the mean value obtained by a suitable damping of the recording device will be too low.

The volume of the escaping fluid and consequently, the decrease in pressure depend on the viscosity. Hence, the values vary according to the viscosity of the fluid. Since, on the other hand, the viscosity of the fluid is greatly affected by temperature, different test results will be obtained at various temperatures. An instrument designed for use on airplanes in flight should not be sensitive to variations of temperature. This fact, which fully explains the experiments previously made with similar measuring devices and which therefore seems to be

reliable, finally settled the question in favor of the stationary measuring box in spite of the attendant difficulties. Thus, the fluid volume can be tightly enclosed, and the results hitherto obtained have fully confirmed our expectations.

The mounting of the whole hub on the shaft without clearance is another difficulty, which must be overcome in order to maintaim equilibrium. On the other hand, the hub should slide freely to insure the passing of all the forces through the measuring device and to prevent their transmission by friction. These two conditions are difficult to coordinate. Former arrangements consisted in mounting a cylindrical sleeve on the shaft stub. The bore of the hub was ground to fit the sleeve exactly. Under these conditions sliding became very difficult, since the sleeve, when firmly secured on the shaft to avoid seizing, expanded and caused jamming. Even grinding, when it is possible, only compensates for the elastic deformation due to the pressure on the cone and not for the deformation by heat. This phenomenon is of minor importance in the case of torque measurements, since the lever arm of the friction forces is so small that no great error can occur. It is otherwise with thrust measurements which depend on the absolute magnitude of the friction. This statement, as will be shown later, applies particularly to the measurement of very small thrusts.

Thus the arrangement of the thrust-measuring hub shown in Figures 1 to 5, was adopted for the mounting of the propeller

on the crank shaft. A flange both in front and aft of the propeller is keyed to the crank shaft. Each flange is provided, on its periphery, with four pairs of rollers mounted on ball bearings. The longitudinally movable portion, into which the propeller blades fit, has four front and rear arms each, fitting in between the pairs of rollers. The whole propeller is mounted on these four arms only and is not otherwise connected with the crank shaft. This arrangement allows for expansion without danger of jamming, especially since the expansion is very small on the periphery of the flanges. Where movable and fixed parts may produce friction by elastic or thermal expansion, they are separated by air.

For transmission of the thrust to the measuring drum, the latter is ring-shaped. Arms of the longitudinally movable propeller pass between the engine shaft and the drum and transmit the thrust to the piston of the measuring drum by means of a thrust ball bearing. The drum is mounted on ball bearings on the sleeve and transmits the axial force through a thrust ball bearing to the flange, which is firmly secured to the crank shaft. The whole action of the force is thus exerted inside of the measuring hub only, so that no force need be transmitted to the outside.

The hub (Fig. 5) is mounted in the usual way, except that a pipe must be run to the observer's cockpit and made fast, in order to prevent the measuring drum from rotating under the ac-

tion of friction in the roller bearings. A rod, fastened to one of the screws on the engine or engine mount, answers the purpose.

The experience gained hitherto with this measuring hub is illustrated by the calibration diagram (Fig. 6). The circles mark points of increasing thrust and the crosses, points of decreasing thrust. There is hardly any internal friction, since there are no deflections in the calibration curve which otherwise would have been produced according to the direction in which the thrust is approached. The curve was plotted on the electric test stand which produces practically no vibration. Friction conditions are certainly as favorable on the vibrating aviation engines. The accuracy of the measurement is therefore chiefly dependent on the accuracy with which a pressure measurement can be made. According to experimental data, the thrust can be measured with an accuracy of 1 to 2 kg (2.2 to 4.4 lb.). Special pressure-measuring devices are used for very small thrust measurements, and the error is then considerably smaller.

The hub has also given satisfactory results on aviation engines in flight. It has now been in operation for approximately 20 hours without the slightest damage. A flight measurement is shown in Figure 7. It is seen that the measured points lie on a curve.

The torque-measuring hub (Fig. 8) was also designed on similar principles. The fluid pressure is measured by means of a stationary

measuring drum. This result was first achieved by converting the tangential force of the engine into an axial force by means of a flange mounted on the engine shaft in front of the propeller. The propeller is rotatable and mounted on ball bearings. The flange carries six pistons. The pistons act on six small boxes secured to the propeller (Figs. 9 and 10). The pressure developed in these boxes is transmitted through a pipe to four other boxes provided with pistons working in an axial direction. All the components participate in the rotation. A specific force in the axially working pistons corresponds to the pressure in the boxes. This force is transmitted by a thrust ball bearing to the ring-shaped stationary measuring drum. The pressure in this drum is measured in the same way as in the thrust-measuring hub. Thus the fluid volumes are all completely enclosed. The pistons of the boxes are ground in and a diaphragm is stretched between the pistons and the fluid, to secure perfect tightness.

At first sight the whole arrangement (Fig. 11) looks more complicated than it really is. The first two sets of boxes merely produce a hydraulic conversion of a force on the principle of the hydraulic press. As in a hydraulic press, the force can also be increased and reduced at will. In the case of the considered hub the force is reduced, primarily to relieve the whole system of excessive axial forces and furthermore, to enable the pressure-measuring devices, used for the thrust-meas-

uring hub, to be likewise used for the measurement of the pressures in the ring-shaped measuring box.

The pressures set up in the rotating fluid and hence also the forces in the axially working pistons are not produced by the pressure of the piston alone, but also by the centrifugal force of the fluid. However, the axial and tangential boxes can be arranged each with respect to the other, so as to eliminate this influence and to render the measurement independent of the centrifugal force. This was actually done in the completed model.

The accuracy of the measuring hub is illustrated by Figure 12. The values designated by small circles were obtained on the electric test stand, and those marked with a cross, on the aviation engine. It appears that even torque measurements can be made with an accuracy which is perfectly satisfactory for technical purposes.

We shall next turn to problems which could not be solved up to the present and which can now be solved by means of these measuring hubs. The most important task would be to use the thrust-measuring hub under conditions corresponding to flight at zero thrust. The pilot is provided with a recording device which enables him to control the number of revolutions by means of the throttle and to reduce the thrust to zero at the desired angle of glide. For the sake of obtaining accurate test results, a measurement will be made for a slightly negative and also

for a slightly positive thrust at the same gliding angle. According to previous tests this can be easily done. The revolution speed at zero thrust materially exceeds the idling speed of the engine, whence it follows that the propeller produces considerable drag at the idling speed.

Such measurements afford means of obtaining the polar of an airplane as if it were flying without a propeller and of checking the usual wind-tunnel tests and aerodynamic calculations with their more or less reliably estimated drag coefficients. A possible objection to such measurements is the way of controlling the number of revolutions by reducing to zero the total thrust over the propeller-disk area, which may be negative about the periphery of the propeller disk and positive toward its center, whereby an error might be incurred, owing to the influence exerted on the airplane. The error, however, is certainly very small. In doubtful cases a special propeller can be so constructed that during gliding tests, the thrust will be zero all over its disk and will leave only a very small residual disturbance.

After thus measuring the airplane polar, we can verify the propeller thrust and the effect of the propeller slipstream on the airplane polar by measuring the same values again with a running engine. Such investigations have already been instituted in the Göttingen wind tunnel and by the D.V.L. in flight, by subjecting airplanes to identical tests by both methods. Torque

measurements which, in addition to propeller tests, can also be used for the determination of engine power as a function of altitude, are likewise very important.

Torque and thrust measurements were separated chiefly for the sake of simplifying the constructional problem. Moreover, this separation constitutes only a slight disadvantage, because most of the tests involve only one of the two factors. Airplane problems involve only the thrust and all engine problems involve only the torque. Thus, all these tests require only the simple installation. Propeller tests alone require both torque and thrust measurements. In such cases the best way is to make two flights, measuring the thrust coefficient during one flight and the torque coefficient of the same propeller during the other flight. In my opinion it is not worth while to seek a complicated solution by a forced combination of the two measurements, since no sufficiently simple solution seems to be available as yet.

The propeller blades were made adjustable in the hubs, on the assumption that the hubs would be used in most cases for airplane and engine tests, the shape of the propeller being of minor importance, provided one is able to take off at all. Thus their use becomes more general, since by changing their pitch they can be easily adapted to different airplanes and engines without requiring new blades in each case. The two models exhibited at the "I.L.A." were designed for metal blades. In

future, hubs will be designed for both metal and wood variable-pitch propellers. Tests of corresponding locking devices are now being made. The chief advantage of wood blades lies in the fact that they are cheap and can be easily modified.

I think I have now mentioned the most important points regarding the problem of the separation of the effect of the engine and propeller, on the one hand, and of the airplane, on the other hand, on the performance of the whole airplane. It only remains for me to mention that my coworker, Mr. Ebert, has had an important share in the development of these measuring hubs. He will also conduct further experiments with them and announce the results at the proper time.

The separation of propeller, engine and airplane effects is far from affording a clear idea of all the forces acting on an airplane. The explanation of their relations requires further force measurements to be made. Surprisingly little work has been done thus far in making force measurements on the various components of an airplane. The only serious attempt to solve this problem was made by Hoff many years ago in the form of rope force measurements. The requisite data for strength calculations were obtained by acceleration measurements. The demand for an accelerometer giving accurate values under practically all conditions is so frequently addressed to the D.V.L. that it inclines me to believe that the actual value of acceleration measurements is being considerably overestimated. Atten-

tion is therefore called to certain points which, although not new, have received too little attention.

An accelerometer always consists essentially of a mass connected by a spring to some part of the airplane. Under the action of acceleration the mass exerts forces on the spring and these forces are measured and recorded by its elongation. Such a system can produce vibrations. When the load is suddenly increased or decreased, it vibrates with a certain frequency which depends primarily on the spring constant and on the magnitude of the mass. According to the elementary principles of the vibration theory, it is a well-known fact that accelerations are accurately measured by such a system, provided the time, during which the measured acceleration increases and decreases is large in comparison with the duration of a natural vibration. The limit of resonance of the accelerometer is reached when these two times become approximately equal. The deflections are then excessive and no readings can be taken. When the acceleration increases and dies away in a time which is short in comparison with the duration of a natural vibration, the recording in strument no longer measures the acceleration but records changes in the position (vibration) of the point where it is attached to the airplane. It thus becomes a vibrograph or seismograph.

Unfortunately, the airplane produces various accelerations with quite different frequencies. The most disagreeable dis-

turbances are due to periodical accelerations set up by the engine vibrations. On present-day engines these accelerations reach frequencies of from 40 to 60 per second and their magnitude at full engine power is usually three to five times that of the acceleration due to gravity. According to the above considerations, accelerometers must be designed with a much higher or a much lower frequency than that of the engine vibrations. Otherwise only a wild vibration will be produced. When higher frequencies are adopted, they should be at least 100 per second in order to lie well outside the range of resonance. Such an accelerometer would then measure all the accelerations of its point of attachment and hence also those engendered by the engine vibrations, which are generally not very important, but cannot be eliminated. They might be damped, but this would also lead to the suppression of all the other vibrations shorter than those of the engine. In that case, the high natural frequency of the accelerometer becomes meaningless, since the unavoidable small deflections require large gearings which cause great constructional difficulties. If, on the other hand, these deflections are not suppressed, the readings taken in flight will be of the type represented in Figure 13. The accelerometer shows an acceleration of approximately 3 to 5 g (acceleration due to gravity) with 30 to 60 periods. The record is a wide band which, according to the accelerations moves upward or downward a distance, which is usually smaller than the width of the band.

Such readings are not of much use. An accelerometer of this type will give good results only when the engine is stopped and the engine vibrations are very small.

The accelerations should furnish a measure for the stress but when they increase and die away quickly they fail to do so. The rather high accelerations, set up by engine vibrations without affecting the construction, confirm this fact. Fatigue failures due to vibrations are not affected by the magnitude of the acceleration but by the number and magnitude of the deflections, which are best measured direct, instead of through the intermediary of acceleration.

When the acceleration measurements are evaluated in the usual way and the acceleration is introduced into the fundamental law of mechanics, force = mass times acceleration (the mass being that of the whole airplane), this holds good, so long as the airplane can be considered as a rigid body. An airplane, however, is actually far from rigid but forms on the contrary a comparatively flexible structure capable of vibrating. The duration of the natural vibrations of monoplane wings is approximately 0.1 to 0.2 of a second. For all phenomena of shorter duration acceleration is no suitable measure of the stress.

According to Hooke's law the tension is proportional to the deformation. When a very great force is exerted on the wing or, in other words, when a very great acceleration is produced, the wing is deflected and the stresses grow in proportion to the

deformation. When, after a short time, the force and hence also the acceleration acting on the wing are suppressed, the wing is deflected still further at first, owing to the inherent kinetic energy, and the stresses are further increased, although there is no acceleration. The force can even be reversed, in which case the wing is further deflected with a correspondingly retarded motion until its maximum deflection is reached. The greatest stresses correspond to this maximum deflection. In the case of the imagined experiment they occur at the moment when the acceleration is zero or has such a sign that the usual evaluation of an acceleration measurement would yield a tension with the contrary sign. This consideration holds good only so long as the acceleration increases and dies away within a time of the same order of magnitude as the duration of a natural vibration.

Short-period accelerations actually occur on an airplane, especially when they are greatest and hence most important. These time limits are closely approached during accelerations in flight, at least for monoplanes. During landing and especially alighting on water, the action of the forces is jerky and under these conditions the idea of acceleration becomes meaningless for the airplane as a whole. Different acceleration values will be obtained at various points of the airplane and no conclusions regarding the stresses can be made until the airplane and its vibration characteristics are known, which will not be soon.

From these considerations it follows that the accelerations are a suitable standard for the measurement of stresses only when they increase from one value to another within a time equal or superior to the period of a natural vibration of the wings, i.e., at least 0.1 to 0.2 of a second. Such accelerations can be easily measured by means of accelerometers with natural frequencies of approximately 20 per second, which, on account of longer oscillations of the springs, can be built in a simpler and handier way. It should, however, always be kept in mind that only comparatively slow phenomena can be studied, for which the acceleration is then also a reliable measure of the stress. Acceleration measurements alone do not afford means of determining stresses during short-period phenomena such as the landing impact. Under these conditions the flattening out after a dive is also a short-period phenomenon for certain airplanes with flexible wings.

These statements are not intended to disparage acceleration measurements. They may be very useful, provided the above conditions are kept in mind. This question was taken up only to show the need of a much more general and reliable method for force measurements. The above-mentioned difficulties and restrictions do not apply to force and elongation measurements, which always afford a reliable criterion for both static and vibrational stresses. Aircraft force measurements are also important for investigating the air flow about airplanes. Thus considerable bene-

fit might be derived from measurements of the forces generated by the tail surfaces in flight, or exerted on seaplane floats during the take-off.

A measuring device suitable for the above purposes should be independent of inertia, shock-proof, accurate, and designed to satisfy all working conditions on airplanes, especially that of occupying only a small space.

The simplest way to determine a force is to measure the elongation of a spring or, which is often better, the actual deformation of a structural part, and to establish by calibration the relation between the force and the elongation. The difficulty lies chiefly in the smallness of the deflections, so that, in order to achieve a reasonable degree of precision, the measurements must be made with an accuracy of at least 0.01 mm (.00039 in.). The work in this connection, especially with electric measuring devices, failed to be satisfactory until Pabst hit upon the idea of scratching the deflections on a plate with a diamond and of then magnifying them with a microscope. Recording devices, as shown in Figure 14, were developed along this line. They satisfy all the above-mentioned requirements and work on the following principle. A spindle, driven by clockwork or by a small motor, moves a slide. This slide carries the plate on which the records are made. Hitherto the best results were obtained with glass plates. The over-all dimensions of the device are 30 x 30 x 50 mm (1.18 x 1.18 x 1.97 in.).

It is secured to some spar or strut at the point where the deflections are to be measured. At a certain distance, say 25 cm (9.84 in.) from the device is secured one end of a rod, the other end of which can move longitudinally and fits into the recording device where it actuates the diamond. The record can be enlarged at will and gives sharp prints up to a 500-fold enlargement. Owing to the fact that the enlargement can be adapted to the requirements, the records can be enlarged at will. Two diagrams of different magnification are shown in Figures 15 and 16.

Tests based on this method are now being instituted for the measurement of landing-gear stresses. Although the method has not yet been applied to all the previously mentioned problems, I am confident it will constitute a means for obtaining most of the experimental data which are still lacking.

Some details are given below on the important question of float and hull resistance, which has hitherto defied mathematical solution. A purely theoretical solution is not likely to be found for a long time. In the meantime we must therefore have recourse to tests. Float-model tests are affected by the difficulty of obtaining mechanical similarity. This feature is also common to other model tests, such as wind-tunnel tests of wings, but it does not greatly affect wind-tunnel experiments in general, and the calculations are fairly reliable, which can not be claimed of water-tank float tests.

According to test results on the effect of the model scale, the coefficients used in float-model investigations are critical values which render scale conversions particularly unsafe. Their untrustworthiness increases with the size of the seaplanes. The large hulls now being built may cause disagreeable surprises. Model tests, however, are far from being useless and should, on the contrary, be more frequently resorted to, in conjunction, however, with full-scale tests.

An installation which seems to suit the purpose is shown in Figure 17. It differs from a normal seaplane only by small frames inserted between the float struts and their points of attachment to the floats. The forces exerted by the floating gear on the floats are transmitted by one horizontal and two vertical steel bands to force-measuring devices. The steel band suspension insures easy, frictionless transmission, so that the forces are fully exerted on the measuring devices. This arrangement enables three-component measurements to be carried out. The whole installation works in two directions and insures a correct recording of the forces, even if they change their sign during the test, which may actually happen when the floats are lifted off the water. The above-mentioned components could be used as the actual measuring devices. The method would consist in transmitting the forces through springs and measuring their elongation, which seems quite feasible, since only very small spring oscillations - 0.5 mm (.0197 in.) - are required. These

instruments are particularly suitable for measurements on rough water, because they are practically unaffected by inertia and because the spring travel is such that the instruments do not affect the elastic properties of the hull.

Fluid measuring boxes seem to be best suited for systematic investigations of the float resistance, which are usually carried out on smooth water, since they enable the recording device to be located in the pilot's or observer's cockpit. The readings, which can be thus taken during the test, are more explicit than subsequent evaluations. The results hitherto obtained with these measuring boxes have the same percentage of accuracy as water-tank tests. The position and the speed of the float on the water must be determined in connection with force measurements. This can be done photographically, while the speed can also be measured with a Pitot tube.

A complete measuring installation of this type is owned by the D.V.L., but no tests have been made for lack of appropriations.

For systematic investigations on a large scale, such an installation must also comprise special floats with an under-water body which, in each case, can be easily and quickly modified without changing the actual framework. The completion of this arrangement should offer no difficulties, since its weight is of minor importance. A great number of current full-size float types could be tested on one seaplane provided with such an

equipment. In the case of very large floats, suitably reduced models could be used.

The D.V.L. installation is designed for airplanes of from 2000 to 3000 kg (4409 to 6614 lb.) total weight. For the largest seaplanes now in use, this represents a model scale of about 1.6 and for the 40-ton Dornier flying boat, under construction, a scale of approximately 2.4. Such scale ratios insure absolutely reliable results. With regard to these tests, which are planned as model tests for very large hulls, it should be noted that the relation between the speed of the model and that of the full-size hull must be as the square roots of the dimensions. The load reduction, due to the wing lift corresponding to each speed, should be produced by suitable variations of the lift which, however, cannot be easily effected. A suggested method consists in mounting on top of a monoplane a second wing of the same area, this wing being easily detachable and having an adjustable angle of attack. This arrangement satisfies all the conditions of flying boats now in operation and of those in course of development. In addition to float strength and resistance, there are many other questions, such as formation of spray, behavior on rough water, drifting before the wind, etc., regarding which this method will afford reliable information.

Translation by W. L. Koporinde,
Paris Office,
National Advisory Committee
for Aeronautics.

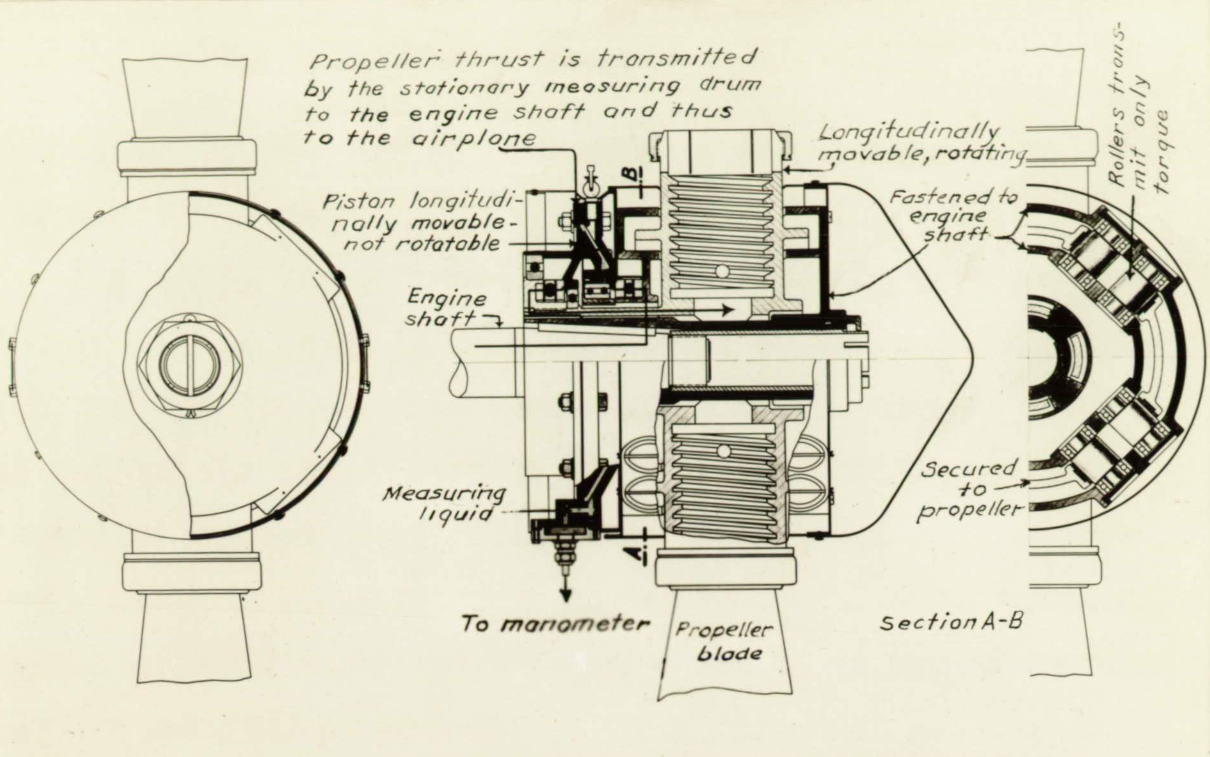

Fig.1 Thrust-measuring hub.

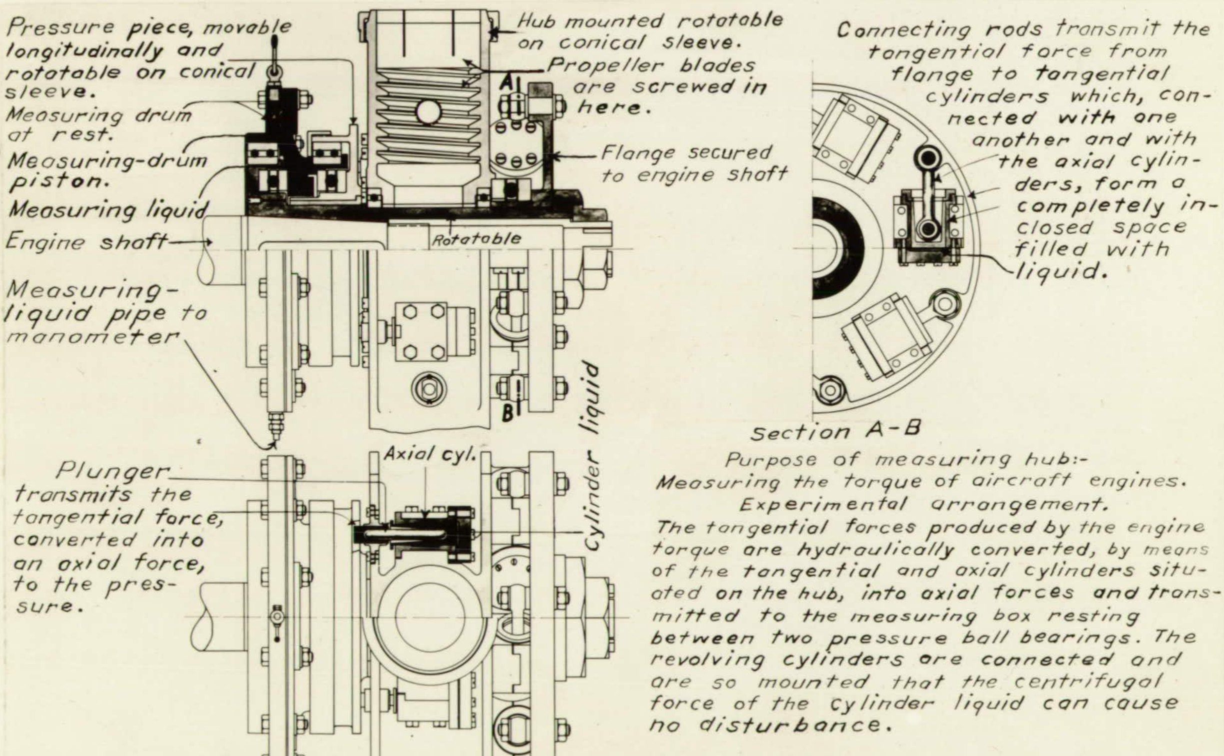

Fig.8 Torque-measuring hub.

Fig.4 Thrust-measuring hub (general arrangement)

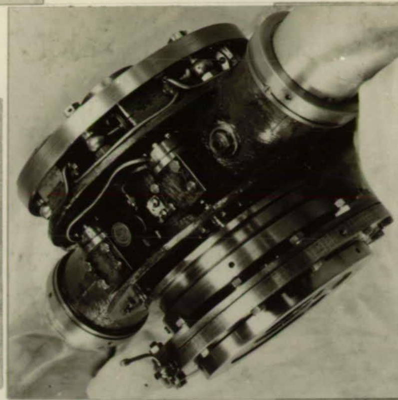

Fig.11 Torque hub (general arrangement)

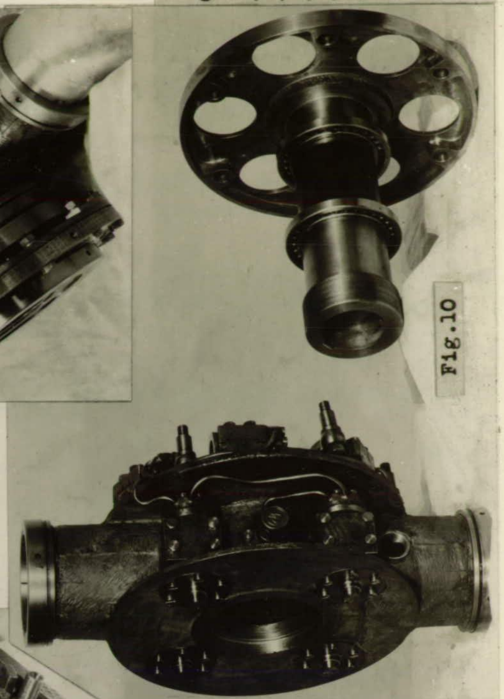

Fig.10

Fig.3 Thrust-measuring hub (central portion movable longitudinally)

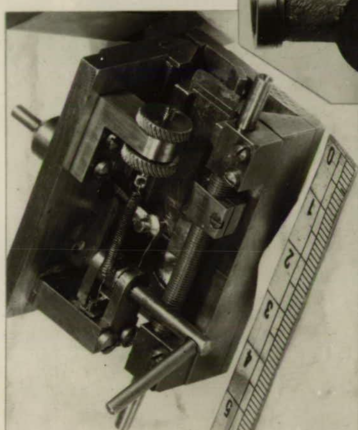

Fig.14 Recording head

Figs.9,10 Torque hub (flange and rotatable part with diaphragm and piston.

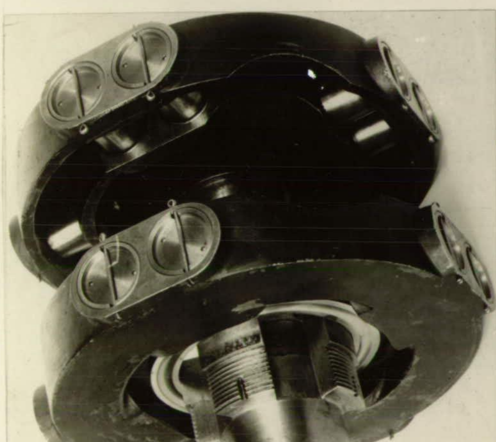

Fig.3 Thrust-measuring hub (portion keyed to engine shaft)

Fig.5 Airplane with thrust-measuring hub.

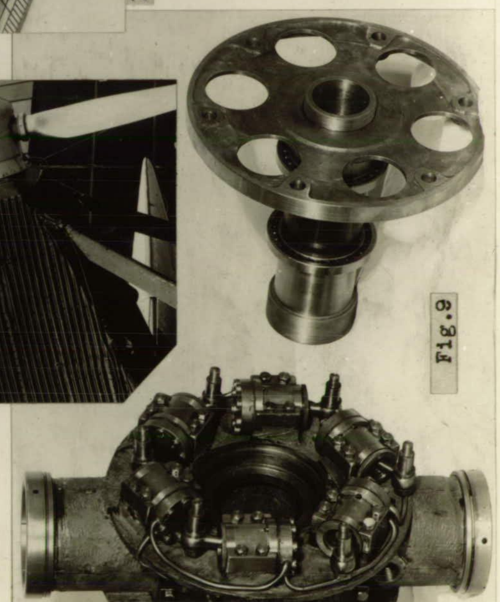

Fig.9

13033 A.S.

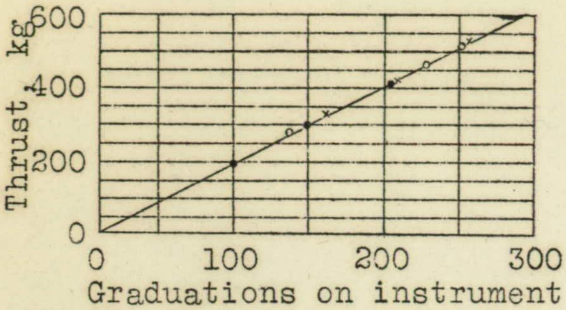

Fig.6 Thrust-measuring hub (calibration curve).

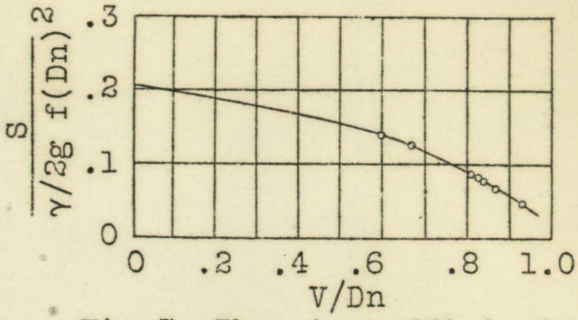

Fig.7 Thrust coefficients measured in flight.

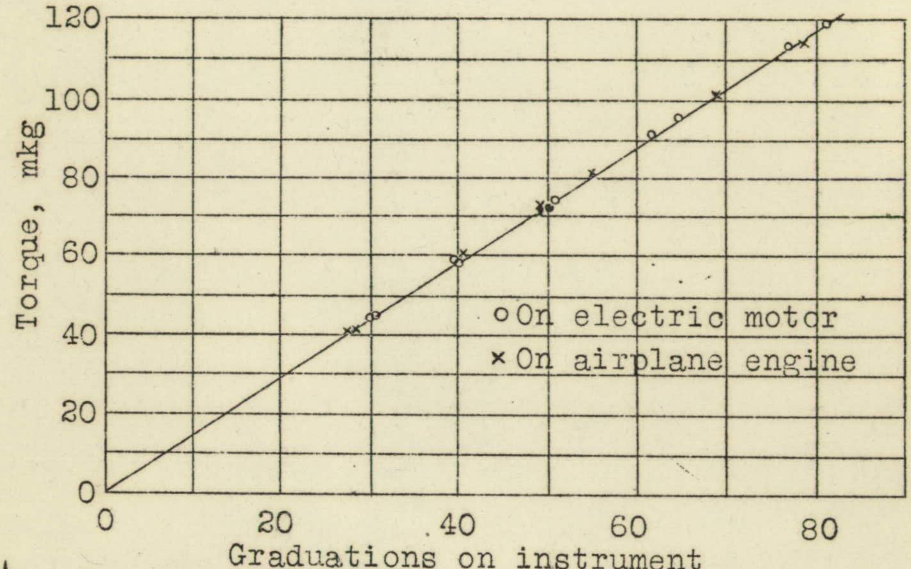

Fig.12 Torque-measuring hub (Results obtained with an electric motor & airplane engine.

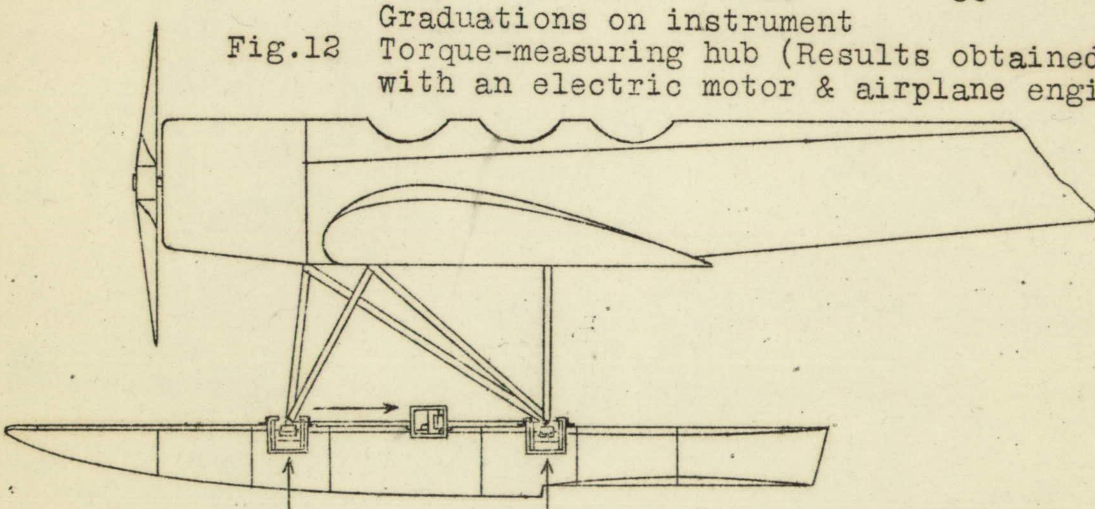

Fig.17 Representation of a test installation for full-size float and hull investigations.

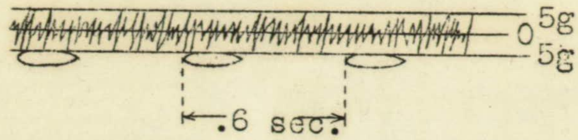

Fig.13 Accelerations in flight with wide-open throttle measured with an accelerometer of high natural frequency.

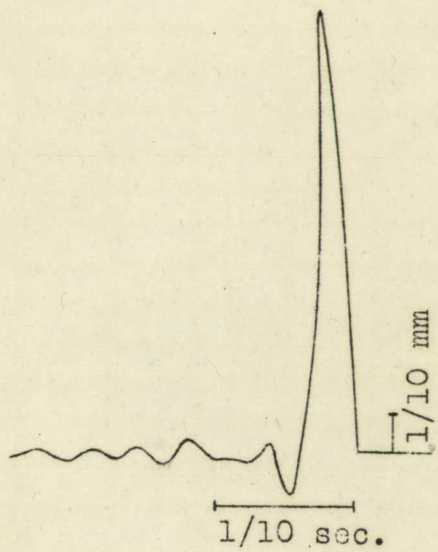

Fig.15 Vibrations of a plate under the action of an impact produced by fluid pressure.

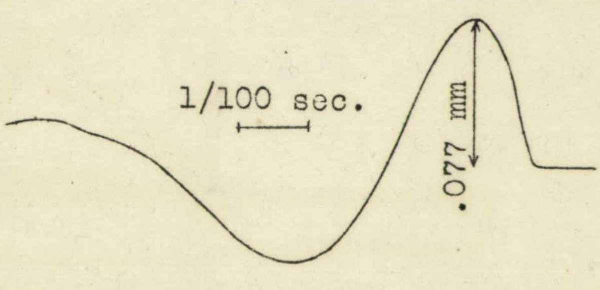

Fig.16 Vibrations of a diaphragm.